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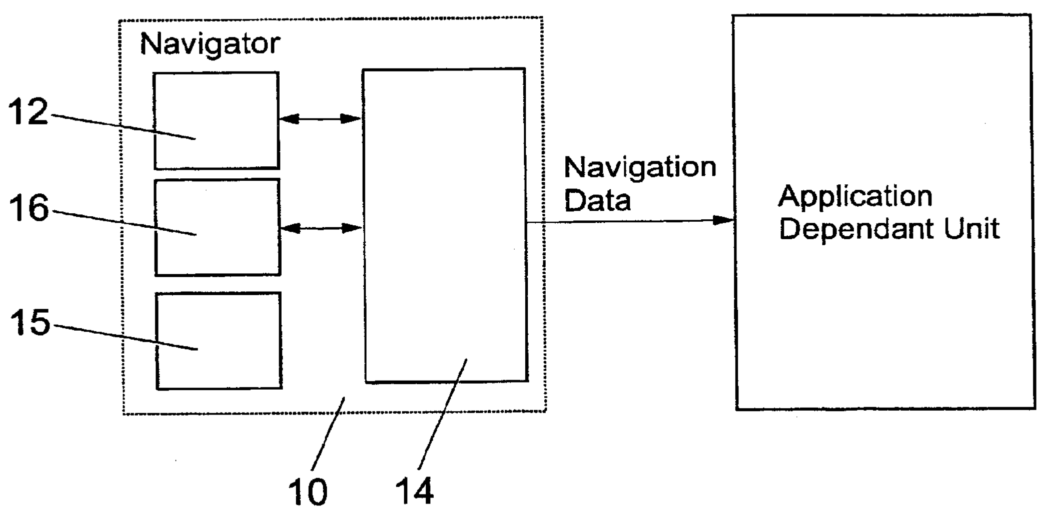
(54) Title: NAVIGATION APPARATUS AND METHOD



(57) **Abstract:** A navigation apparatus and method is described as comprising an inertial navigation sensor having a data output, and a processor adapted to be coupled to the data output. The processor is capable of performing a non-linear processing of the data output. Preferably, the apparatus and method are characterised in that a GPS (or similar satellite system) is provided where data output from the GPS is provided to the processor. Preferably, the apparatus and method are further characterised in that the processor comprises an artificial neural network, and the inertial navigation sensor is moved between at least two known locations during the training of the artificial neural network.

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"Navigation Apparatus and Method"

The present invention relates to a navigation apparatus and method, and more particularly, but not exclusively, relates to a navigation apparatus and method for a wide range of applications such as vehicles, such as motor cars, motor bikes, boats, ships, vans, lorries, trains, aircraft, hovercraft, balloons, gliders and the like, or any application which requires a navigational reference platform, as well as other applications such as drilling boreholes in the ground for purposes such as the exploration of hydrocarbons and other applications where knowledge of the navigation of a person or object is required, such as munitions, ordinance, missiles, rocketry and any other military or civilian application, as well as subsea and underwater vehicles, humans under ground, animals such as wildlife tagging etc.

The majority of commercial aircraft utilise an Inertial Navigation System (INS) to permit the pilot to navigate the aircraft entirely independently of any external reference signals such as the Global Positioning System (GPS) operated by the United States Department Of Defence (USDOD) or the many different aviation

navigation beacons that are available. INS was originally developed for intercontinental ballistic missiles and comprises a series of two or three orthogonally mounted gyroscopes and three accelerometers to measure minute changes in the vehicle's acceleration; in other words, the gyroscopes and accelerometers measure very small angular rotations and g-forces. By mathematically or electronically integrating these g-forces, the INS is able to determine positional changes in the vehicles position, and given a known starting location, the INS the current position can be determined.

However, the mathematical process of integration of the vehicle acceleration unavoidably involves small errors due to the mechanical tolerances involved in the gyroscopes and accelerometers. These small errors, when integrated and multiplied by time to compute the positional variations of the vehicle, cause a long term "drift" in the calculated position of the INS. An aircraft, using a commercial INS unit, crossing the Atlantic from Heathrow airport can be 3km away from its true position when it finally reaches the East coast of the USA.

Furthermore, commercial aviation INS cost upwards of US$ 100,000 and are therefore aimed at professional, safety critical applications.

Satellite navigation systems, such as the US Navstar GPS, the Russian GLObal Navigation System (GLONASS) and the European Geostationary Navigation Overlay Service (EGNOS) are also well known. The GPS in particular has already revolutionised the ground transportation sector, and GPS can commonly be found on-board cars, trucks, boats and small aircraft and are widely used by

recreational sailors, climbers and hikers. Key factors of the success of GPS are the low-cost and miniaturisation of the GPS receivers. However, because of their poor short-term navigation performance and the requirement to always have a number of the Navstar satellites in sight, navigation applications based on GPS receivers are in fact limited. Furthermore, GPS suffers from the well known "Urban Canyon" effect which results from the screening of the GPS antenna by the buildings in a typical urban city centre. In fact, the GPS signal level is very low, and almost any obstruction such as a tree branch will attenuate the signal sufficiently to prevent reception of the signal from the satellite by the GPS receiver. Furthermore, the USDOD has prevously applied Selective Availability (SA) to the GPS signal, where SA is a deliberate degradation intended to deny access to the full GPS accuracy to non-US approved personnel. SA imposes a 100m 95% Circle Error Probability (CEP), which means that 95% of the reported positions from a GPS receiver should be within 100m of the true location. This does not take into account signal degradation due to propagation or geometrical precision dilution effects.

INS provides accurate information on position, speed and attitude, at a relatively high rate, but is only generally effective over short periods due to the accumulation of the INS sensor errors. A GPS receiver with a single antenna can provide position and speed, but if there are only three satellites in the line of sight of the antenna then the GPS generally cannot provide attitude although it can do so if there are four satellites in the line of sight of the antenna. The GPS provides this data at a relatively low rate, but with excellent long term position accuracies.

It is therefore desirable, for applications where it is possible to use GPS, to integrate the output of the INS and GPS to combine the advantages of both systems whilst avoiding many of the disadvantages of each system in isolation. A conventional way of doing this, particularly for military applications is to use a Kalman Filter which takes two independent measurements of the same quantity, where each of the two measurements has its own independent error sources, and integrates them together to provide an improved estimate of the quantity with an associated error less than or equal to either of the original errors. A detailed understanding of the mathematics behind Kalman Filters reveals that the two criteria that are important for the operation of a Kalman Filter are the independence of the error sources and the linearity of the sensors. Therefore, if the error sources are not independent, or the sensors are non-linear, then the estimate will be worse than either of the original estimates, not better. Conventional INS devices are linear and are thus suitable for use with a Kalman Filter.

According to a first aspect of the present invention, there is provided a navigation apparatus comprising an inertial navigation sensor having a data output, and a processor adapted to be coupled to the data output, the processor being capable of performing a non-linear processing of the data output.

According to a second aspect of the present invention, there is provided a method of providing navigation information, the method comprising providing an inertial navigation system having a non-linear output, and processing the non-linear output with a processor.

Preferably, the first and second aspects of the invention are characterised in that a GPS (or similar satellite system) is provided where data output from the GPS is provided to the processor.

Preferably, the first and second aspects of the invention are further characterised in that the processor comprises an artificial neural network, and the inertial navigation sensor is moved between at least two known locations during the training of the artificial neural network.

Typically, a portion or all of the processing may be conducted in a simulated manner. Alternatively, the processing may be conducted by a processor mounted on the apparatus.

Preferably, a GPS (or similar satellite system) may also be provided where data output from the GPS is provided to the processor.

Typically, the processor is a pattern classifier processor, and preferably includes an artificial neural network.

Preferably, the navigation apparatus is provided within a housing which may be mounted on an object, person, animal, tool, vehicle, or any item for which knowledge of its navigation is desired.

Preferably, the inertial navigation sensor comprises two, or more preferably three orthogonally arranged sensors. Preferably, the inertial navigation sensors are solid-state devices and more preferably, are solid-state accelerometers which may comprise a silicon etching formed in silicon wafer.

The advantage of using such a solid state accelerometer is that it is relatively inexpensive.

The artificial neural network may optionally be in the form of a Kohonen Feature map or Self-Organising Map (SOM).

The artificial neural network is typically trained initially, and typically has a training phase performed upon it.

Typically, the patterns used to train the artificial neural network represent pattern that will be observed in the real data used during the "execution" phase of operation. Preferably, many training cycles are conducted during the training phase.

Preferably, the artificial neural network is trained in an unsupervised manner. Typically, data representing the known location is input to the artificial neural network during the labelling phase of the unsupervised training.

Alternatively, the artificial neuron network is trained in a supervised manner.

With regard to supervised training, preferably by use of a Backpropagation algorithm, the artificial neuron network adjusts its internal weights. Preferably, data representing the known locations is input to the artificial neural network, prior to the next set of data for the next location being input from the inertial navigation sensor, such that the artificial neural network learns the difference between the output of the inertial navigation sensor versus the data representing the known location.

Typically, the inertial navigation sensor is moved between many known locations of a track, such as a track arranged within a laboratory, where the spacial location of many points on the track have been previously and accurately surveyed.

Embodiments of the present invention will now be described, with reference to the accompanying drawings, in which:-

Fig. 1 is a block diagram of a navigation system in accordance with the present invention; and

Fig. 2 is a schematic representation of a portion of a Neural Network for illustrative purposes.

Fig. 1 shows a schematic block diagram of the main components of a navigation system 10 in accordance with the present invention. The navigation system optionally comprises a commercially available GPS or DGPS receiver 12, where data output of this optional GPS/DGPS receiver 12 is connected by any suitable means such as electrical wiring to a processing module 14. An electrical power supply 15, which may be any suitable power supply, is also provided.

An INS 16 is also provided, and has its data output connected by any suitable means to the processing module 14. The INS 16 preferably comprises three orthogonally arranged miniature solid-state accelerometers, examples of which are manufactured by ANALOGUE DEVICES, in that the three accelerometers are mounted perpendicularly to one another. Additionally, the INS 16 comprises two orthogonally mounted gyroscopes which can be used to measure the rotation of the INS.

The solid state accelerometer 16 comprises a sub-

miniature silicon "beam" etched into the silicon wafer. The beam deflects or bends under the applied g-forces experienced by the INS 16, and the deflection of the beam can be measured by a number of methods electronically.

The advantage of using such a solid state accelerometer is that it is relatively inexpensive. Hitherto, such solid state accelerometers have only been known for use in the anti-shake "Steady Shot" mechanisms utilised in consumer handheld camcorders, and such solid state accelerometers are extensively non-linear in that there is not a linear relationship between the acceleration and the output voltage. In other words, if the acceleration is doubled, the output voltage does not double, but rather varies in a complex manner with acceleration. Furthermore, such solid state accelerometers suffer from a pronounced resonant frequency as a result of the dimensions of the silicon beam employed in the accelerometer, which produces a marked non-linearity in the sensitivity of the device under vibrational conditions. As a result, such solid state accelerometers have hitherto been considered to be entirely unsuitable for use within an INS environment.

The processing module 14 comprises a non-linear processor, which is in essence a pattern classifier, in the form of an Artificial Neural Network (ANN). Depending upon which training method is to be utilised (details of which follow) the ANN may be in the specialised form of a Kohonen Feature map or Self-Organising Map (SOM).

The ANN comprises a networked array of neurons, and in its hardware implementation, the number of neurons is

only limited by the number that can be provided on a silicon chip. At present, it is proposed to use a silicon chip with 256 neurons thereon, but this figure will increase substantially over time as the technology improves.

The ANN effectively has two phases of operation, these being "training" and "execution" and which will be detailed subsequently. The ANN requires to be trained on example data, and this will also be detailed subsequently.

The ANN 14 is a probabilistic device with each neuron in the network being initialised with a series of random "weights", where the weights determine the relationship between the different inputs fed to a neuron. As a result, the convergence on the patterns in the input data is purely one of statistical chance. For example, with a particular distribution of initial weights, on one occasion the ANN 14 may converge on a particular pattern in the input data set, and on another occasion with a different weight distribution, this pattern may be missed.

The patterns used to train the ANN 14 should be typical of the patterns that will be observed in the real data used during the "execution" phase of operation. It should be noted that the quality or relevance of the training data will have a major impact on the capability of the ANN 14 during execution. If the ANN 14 has not been trained on data containing examples of patterns that are of interest, then it will be unable to identify such patterns in the execution phase. Additionally, like biological neural systems, the ANN 14 must be shown many examples of the training data, and it may be necessary to have a training run

containing hundreds of thousands of cycles.

Initially, the ANN 14 requires to be trained on example data, and there are typically two different methods of training the ANN 14, supervised and unsupervised.

With regard to supervised training, the input data are fed from the GPS/DGPS 12 (if present) and/or the INS 16 into the ANN 14, while the known location of the navigation system 10 (which is known from previously conducting an accurate survey of the location) is also fed to the ANN 14. The ANN 14 then attempts, by use of a Backpropagation algorithm as described by J.J. Hopfield, "Neural networks and physical systems with emergent collective computational abilities" in the Proceedings of the National Academy of Sciences 79:2554-2558, 1982, to adjust its internal weights so as to best represent the input data. The navigational system 10 may be moved through a number of known locations and hence the ANN 14 will be receiving data from the GPS/DGPS 12 (if present) and/or the INS 16, each of which represent an independent estimate of the position of the system 10. However, it should be borne in mind that each of the two data sets contain errors, in that the data are "noisy". At each training step, the actual location is fed to the ANN 14 and the ANN 14 attempts to adjust its internal weights so that its output is close to the actual location value.

After sufficient training of the ANN 14 has occurred, in that the ANN 14 understands the relationship between the GPS/DGPS (if present) and/or INS data, the training phase is concluded and the execution phase is commenced.

The execution phase consists of moving the navigation

system 10 to an unknown location and the ANN 14, since it understands the relationship between the GPS/DGPS 12 (if present) and/or the INS 16, will provide an output that represents the corrected position of the navigational system 10. It should be noted that this positional estimate will be subject to error in the same way as before.

In order to clarify the nature of the supervised method of training, an example is now given of a training exercise for another application, specifically Optical Character Recognition (OCR). In this OCR application, data are provided by either a digital camera, or a scanner positioned over the character to be recognised. Fig. 2 shows a typical arrangement for an ANN 20 used in an OCR application, where the data provided by the camera or scanner are input into the ANN 20 at locations 18a to 18z. The data input will usually be in the form of pixel data from the camera. The ANN 20 has a number of outputs A to Z, each representing a letter from the alphabet. The ANN 20 further comprises an array of neurons 22 which are networked. In general, the desired result in this OCR application is that when the camera/scanner views the letter A, the A output of the ANN 20 should be activated whilst the other B to Z outputs are not active. The ANN 20 is "trained" by inputting the pixel data for the letter A into the inputs 18a to 18z. The weights in the neurons 22 are initially random, with the result that the outputs A to Z indicate a random pattern. The desired output of A is now shown to the ANN 20, and by using its training algorithm, such as the Backpropagation algorithm as described in the aforementioned J.J. Hopfield publication, the ANN 20 tries to adjust its weights so as to make the A output a 1 (that is, active) and the B to Z outputs a 0 (that is, inactive).

The training is continued by showing the ANN 20 thousands of examples of the letter A as well as the letters B to Z. For each time that the ANN 20 is input with data relating to a letter, the ANN is shown what the correct result should be. As training is progressed, the ANN should start to converge on the correct result, and hence no longer outputs a random result, such as when the ANN is shown the letter A, the A output is close to a 1 whilst the B to Z outputs are close to 0. The more training that is given to the ANN 20, then the accuracy of the ANN 20 will increase, until the accuracy is acceptable, at which stage, the training phase can be stopped, and the execution phase can be commenced.

In the execution phase, the ANN 20 is now shown an unknown letter (i.e. form a text that is to be the subject of the OCR) by having the pixel data fed into the inputs 18a to 18z. The correct output should be close to a 1 whilst the other outputs should all be close to a zero.

With regard to the unsupervised training method, this requires the ANN 14 to be in the specialised form of the SOM. This unsupervised training method does not require training data to be used, but rather the SOM attempts to form internal classifications of significant clusters of data observed in the input data. The SOM 14 is trained by moving the navigational system 10 through a wide variety of unknown positions, without showing the SOM 14 at each location what the correct value is for the location. The SOM 14 then classifies the relationships between the input data in a suitable manner, such as described in Tuero Kohonen "Analysis of a Simple Self-Organising Process" Biological Cybernetics 44(2):135-140, 1982 publication.

Once sufficient training cycles have been completed, the SOM 14 is then subjected to a "labelling" phase, which consists of moving the SOM 14 through a number of known test locations which have been previously accurately surveyed. This knowledge of the spacial location of the test locations is used to label the activated SOM 14 neurons in an appropriate manner, such as described in Tuero Kohonen "Self-Organising Maps" Springer Series in Information Sciences, 1995. After this labelling phase has been concluded, the weights of the neurons in the SOM 14 are "frozen", and the SOM 14 can enter the execution phase.

Use of the navigation system 10 is now permitted, since the GPS/DGPS 12 (if present) and/or the INS 16 provide data to the SOM 14 which has been trained to recognise the relationship between the SA GPS/DGPS 12 (if present) and the non-linear and resonant INS 16. Hence, the SOM 14 output provides an improved estimate of the position of the navigational system 10 since the SA error experienced by the GPS 12 is entirely independent of the non-linearity and resonance experienced by the INS 16.

In order to clarify the nature of the unsupervised method of training, an example is now given of a training exercise for another application, specifically facial recognition. An SOM used in that application may be shown thousands of faces without telling the SOM which face belongs to which person. The SOM will hopefully classify faces from the same person into the same category, and those of different people into respective different categories. After this training phase has been concluded, the labelling phase is commenced in which the SOM is shown individual examples (only one is required) of each of the faces. Then

observation is done for the clusters of neurons in the SOM which are activated or excited by that face, and those clusters of activated neurons are labelled to represent the name of the person whose face is being used.

It should be noted that there is a great advantage in using the unsupervised method of training for the ANN/SOM 14, in that the initial training phase can be conducted in a simulation environment by computer, which enables extensive training of the SOM to be undertaken with minimal inconvenience. The simulation environment contains a mathematical model of the INS 14 and the GPS 12 (if present), where the mathematical model is created using the manufacturer's specifications. The simulated navigational system 10 is taken over a varied and extensive training track within the simulation environment. During this training the outputs of the GPS 12 and INS 16 are computed and fed into the program which is simulating the SOM 14. A suitable program for simulating the SOM 14 is MATLAB (RTM) which is offered by THE MATH WORKS, INC. Hence, the simulated SOM 14 "learns" about the relationship between the INS 16 and the GPS 12, including the effects of INS drift and GPS SA. Typically, thousands of training cycles will be required in the simulation.

The simulation models are, however, inevitably somewhat limited in accuracy. For this reason, a physical navigation system 10 is created, and the physical SOM 14 is initialised using the data from the simulation; that is the simulated SOM 14 neuron weights. These simulated data provides a good starting point, since the INS 16 and GPS 12 models are reasonably accurate. Hence, the final training required to optimise the SOM

weight vectors is much reduced. The final training of the SOM 14 is concluded in the same manner as detailed above.

Once the SOM 14 of the test rig has been fully trained, the SOM 14 weight vectors can be transferred to production units manufactured by mass production techniques. These production units do not require significant additional training since the weights from the SOM 14 of the test rig represent the relationship between the GPS 12 and INS 16 modules.

In practice, there may be some variation between production solid-state sensors due to the natural manufacturing tolerances. Post-production training can be conducted in a similar manner to the test rig training if required.

Tests have been conducted that reveal that given a known starting point (to take out the effects of GPS SA), the navigational system 10 experiences a 30cm/hour short term drift. Long term drift is limited by the basic GPS accuracy of 1-3 metres. Therefore, during "urban canyons", the INS provides good short term accuracy of 30cm/hour. Over longer term use, there should be a maximum drift of 3 metres assuming that the GPS 12 is present. Furthermore, the SA is removed because of its semi-periodic nature, with the INS 16 providing the short term navigational reference.

It should be noted that the GPS 12 could be omitted from the navigation system 10, and the navigation system 10 could be used for applications where there is no line of sight to a GPS Navstar satellite, such as included in a downhole string which is inserted into a borehole in the earth such as an oil or gas well, since

the INS 16 will provide at least a reasonable short term accuracy.

Furthermore, it is envisaged at present that the ANN/SOM 14 will be implemented in a hardware unit. However, it is also foreseen that a software implementation of the ANN/SOM 14 could be achieved, where the software program is run on Digital Signal Processing (DSP) chips as these become more powerful in order to allow a real time software implementation.

Modifications and improvements can be incorporated without departing from the scope of the invention. For instance, the navigation system 10 could be incorporated into a vehicle (not shown) to permit an operator of the vehicle to monitor the speed of the vehicle, thus gaining independence from the conventional vehicle electronics which currently monitor the speed.

CLAIMS

1. A navigation apparatus comprising an inertial navigation sensor having a data output, and a processor adapted to be coupled to the data output, the processor being capable of performing a non-linear processing of the data output, characterised in that a GPS (or similar satellite system) is provided where data output from the GPS is provided to the processor.

2. Apparatus according to claim 1, wherein a portion or all of the processing is conducted in a simulated manner.

3. Apparatus according to claim 1, wherein the processing is conducted by a processor associated with the apparatus.

4. Apparatus according to any preceding claim, wherein the processor is a pattern classifier processor.

5. Apparatus according to any preceding claim, wherein the processor comprises an artificial neural network.

6. Apparatus according to any preceding claim, wherein the navigation apparatus is provided within a housing which is mounted on an object, person, animal, tool, vehicle, or any item for which knowledge of its navigation is desired.

7. Apparatus according to any preceding claim, where the inertial navigation sensor comprises three orthogonally arranged sensors.

8. Apparatus according to claim 7, wherein the inertial navigation sensors are solid-state devices.

9. Apparatus according to claim 7, wherein the inertial navigation sensors are solid-state accelerometers.

10. Apparatus according to claim 9, wherein the solid-state accelerometers comprise a silicon etching formed in silicon wafer.

11. Apparatus according to claim 5, wherein the artificial neural network is in the form of a Kohonen Feature map.

12. Apparatus according to claim 5, wherein the artificial neural network is in the form of a Self-Organising Map (SOM).

13. Apparatus according to any of claims 5, 11 or 12, wherein the artificial neural network has a training phase performed upon it.

14. Apparatus according to claim 13, wherein patterns used to train the artificial neural network represent patterns that will be observed in the real data used during the "execution" phase of operation.

15. Apparatus according to either of claims 13 or 14, wherein the artificial neural network is trained in an unsupervised manner.

16. Apparatus according to either of claims 13 or 14, wherein the artificial neuron network is trained in a supervised manner.

17. Apparatus according to claim 16, wherein a Backpropagation algorithm is utilised, whereby the artificial neuron network adjusts its internal weights.

18. A method of providing navigation information, the method comprising providing an inertial navigation system having a non-linear output, and processing the non-linear output with a processor, characterised in that a GPS (or similar satellite system) is also provided where data output from the GPS is provided to the processor.

19. A navigation apparatus comprising an inertial navigation sensor having a data output, and a processor adapted to be coupled to the data output, the processor being capable of performing a non-linear processing of the data output, characterised in that the processor comprises an artificial neural network, and the inertial navigation sensor is moved between at least two known locations during the training of the artificial neural network.

20. Apparatus according to claim 19, wherein a portion or all of the processing may be conducted in a simulated manner.

21. Apparatus according to claim 19, wherein the processing is conducted by a processor associated with the apparatus.

22. Apparatus according to any of claims 19 to 21, wherein a GPS (or similar satellite system) is also provided where data output from the GPS is provided to the processor.

23. Apparatus according to any of claims 19 to 22,

wherein the navigation apparatus is provided within a housing which is mounted on an object, person, animal, tool, vehicle, or any item for which knowledge of its navigation is desired.

24. Apparatus according to any of claims 19 to 23, wherein the inertial navigation sensor comprises three orthogonally arranged sensors.

25. Apparatus according to claim 24, wherein the inertial navigation sensors are solid-state devices.

26. Apparatus according to claim 25, wherein the solid-state devices are solid-state accelerometers.

27. Apparatus according to either of claims 26, wherein the solid-state devices comprise a silicon etching formed in silicon wafer.

28. Apparatus according to any of claims 19 to 27, wherein the artificial neural network is in the form of a Kohonen Feature map.

29. Apparatus according to any of claims 19 to 27, wherein the artificial neural network is in the form of a Self-Organising Map (SOM).

30. Apparatus according to any of claims 19 to 29, wherein patterns used to train the artificial neural network represent patterns that will be observed in the real data used during the "execution" phase of operation.

31. Apparatus according to any of claims 19 to 30, wherein many training cycles are conducted during the training phase.

32. Apparatus according to any of claims 19 to 31, wherein the artificial neural network is trained in an unsupervised manner.

33. Apparatus according to any of claims 19 to 31, wherein the artificial neuron network is trained in a supervised manner.

34. Apparatus according to claim 33, wherein a Backpropagation algorithm is utilised, wherein the artificial neuron network adjusts its internal weights.

35. Apparatus according to claim 33, wherein data representing the known locations is input to the artificial neural network, prior to the next set of data for the next location being input from the inertial navigation sensor, such that the artificial neural network learns the difference between the output of the inertial navigation sensor versus the data representing the known location.

36. Apparatus according to claim 32, wherein data representing the known location is input to the artificial neural network during the labelling phase of the unsupervised training.

37. Apparatus according to any of claims 19 to 36, wherein the inertial navigation sensor is moved between many known locations of a track.

38. A method of providing navigation information, the method comprising providing an inertial navigation system having a non-linear output, and processing the non-linear output with a processor, characterised by the processor comprising an artificial neural network, and moving the inertial navigation sensor between at

least two known locations during the training of the artificial neural network.

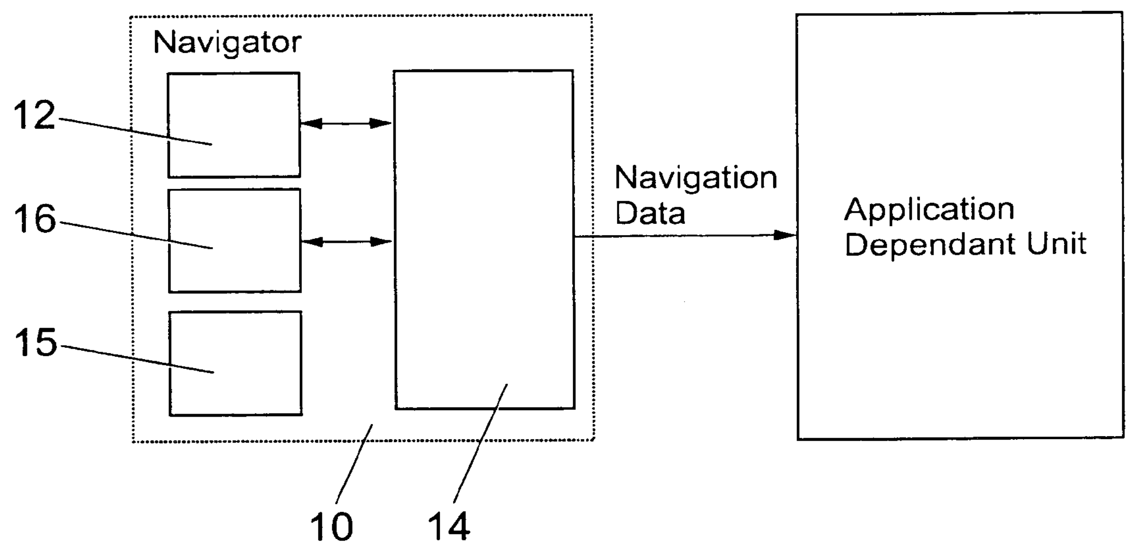
Navigator
12
16
15
Navigation
Data
Application
Dependant Unit
10
14

Fig. 1

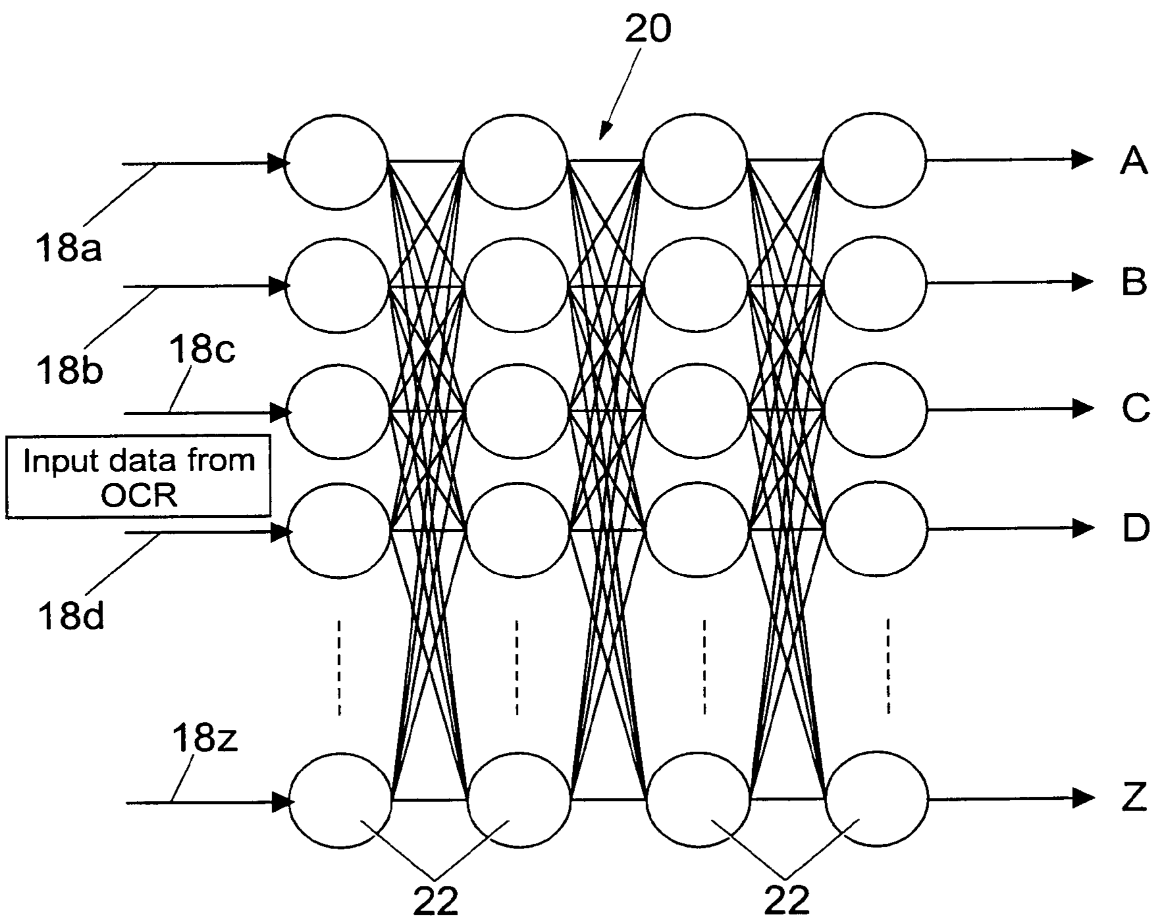

Fig. 2

INTERNATIONAL SEARCH REPORT

International Application No
PCT/GB 00/01966

A. CLASSIFICATION OF SUBJECT MATTER
IPC 7 G01S5/14 G01C21/16

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)
IPC 7 G01S G01C

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practical, search terms used)

WPI Data, EPO-Internal, PAJ, INSPEC

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category °	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	US 5 654 890 A (LOSS KEITH R ET AL) 5 August 1997 (1997-08-05) figure 1 column 3, line 56 - line 61	1-3,5,6, 18
A	column 9, line 41 - line 53 column 10, line 60 - line 67	19-38
X	EP 0 763 712 A (UNION SWITCH & SIGNAL INC) 19 March 1997 (1997-03-19) abstract	1-6, 19-23,38
A	column 2, line 25 - line 38 column 4, line 46 - line 53 column 5, line 39 - line 48 column 6, line 10 - line 18	24-37

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[X] Further documents are listed in the continuation of box C.

[X] Patent family members are listed in annex.

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"A" document defining the general state of the art which is not considered to be of particular relevance

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Date of the actual completion of the international search	Date of mailing of the international search report
15 September 2000	28/09/2000

Name and mailing address of the ISA	Authorized officer
European Patent Office, P.B. 5818 Patentlaan 2 NL - 2280 HV Rijswijk Tel. (+31-70) 340-2040, Tx. 31 651 epo nl, Fax: (+31-70) 340-3016	Ó Donnabháin, C

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